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AVIONICS COST DEVELOPMENT FOR CIVIL APPLICATION OF GLOBAL POSIT--ETC(U)

JUL 78 S H KOWALSKI

DOT-FA76WA-3788

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**INTERIM REPORT
AVIONICS COST DEVELOPMENT FOR
CIVIL APPLICATION
OF GLOBAL POSITIONING SYSTEM**

July 1978

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**Prepared for
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
OFFICE OF SYSTEMS ENGINEERING MANAGEMENT
WASHINGTON, D.C. 20591
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SUMMARY

This study of costs for avionics for civil use of the Global Positioning System (GPS), performed for the FAA Office of Systems Engineering Management (OSEM), was based on a uniform approach to cost estimating with the assistance of a pricing model.

The system evaluated is the military-developed "Z" set with appropriate packaging modifications to meet the requirements of air carrier avionics standards and the less stringent environmental and packaging requirements of general aviation.

The adaptation of the "Z" set for civil applications of GPS has resulted in a navigation system that will provide accurate position information to aircraft in flight as well as the capability equivalent to an area navigation (RNAV) system.

The civil GPS system requires a receiver, control and display unit, antenna, and a preamplifier. High-performance aircraft would probably have one set of each installed in conventional locations within the air frame if redundancy is not required. Low-performance aircraft would probably use a combined antenna-preamplifier package, with the receiver remotely mounted and the control in the console of the aircraft. The expected costs of the avionics required by each of the three civil aviation communities -- the air carriers, high-performance general aviation, and low-performance general aviation -- are shown in Table S-1. The costs are in 1977 dollars, without inflation, and based on annual production quantities of 1000 units.

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Table S-1. ACQUISITION COST OF GPS AVIONICS			
Equipment	Cost (in Dollars) by User Category		
	Air Carrier	High-Performance General Aviation	Low-Performance General Aviation
Receiver	9,812	12,756	2,746
Control and Display	1,300	1,690	724
Preamplifier	727	945	150
Antenna	230	299	
Total Cost	12,069	15,690	3,620

CONTENTS

	<u>Page</u>
ACKNOWLEDGEMENT	iii
SUMMARY	v
CHAPTER ONE: INTRODUCTION	1-1
1.1 Background	1-1
1.2 Project Overview	1-1
1.3 Organization of the Report	1-2
CHAPTER TWO: PRICING METHOD AND THE PRICE MODEL	2-1
2.1 Cost Estimating Method	2-1
2.2 The Price Model	2-2
2.2.1 Model Input Data	2-2
2.2.2 Model Output Data	2-2
CHAPTER THREE: GLOBAL POSITIONING SYSTEM (GPS) CIVIL AVIONICS	3-1
3.1 Avionics Cost Development, High-Performance Aircraft	3-1
3.1.1 GPS Receiver	3-2
3.1.2 GPS Control and Display	3-3
3.1.3 GPS Preamplifier	3-7
3.1.4 Cost Summary	3-7
3.2 Avionics Cost Development, Low-Performance Aircraft	3-8
3.2.1 GPS Receiver	3-8
3.2.2 GPS Control and Display	3-11
3.2.3 Cost Summary	3-13
CHAPTER FOUR: RESULTS OF EVALUATION	4-1
4.1 Concept Evaluated	4-1
4.2 Cost Data of Concept Evaluated	4-1
APPENDIX A: RCA PRICE MODEL INPUT PARAMETERS	A-1

LIST OF TABLES

	<u>Page</u>
S-1. Acquisition Cost of GPS Avionics	vi
2-1. Key Price Physical and Economic Descriptors	2-3
3-1. Parameter Values for GPS Receiver, High-Performance Aircraft	3-4
3-2. GPS Receiver, High Performance Aircraft (1977 Dollars)	3-5
3-3. Parameter Values for Control and Display, High-Performance Aircraft	3-6
3-4. GPS Control and Display, High-Performance Aircraft (1977 Dollars)	3-7
3-5. GPS Avionics, High-Performance Aircraft, Single System	3-8
3-6. Parameter Values for GPS Receiver, Low-Performance Aircraft	3-10
3-7. GPS Receiver, Low-Performance Aircraft (1977 Dollars)	3-11
3-8. Parameter Values for Control and Display, Low-Performance Aircraft	3-12
3-9. Control and Display, Low-Performance Aircraft (1977 Dollars)	3-13
3-10. GPS Avionics, Low-Performance Aircraft, Single System	3-13
4-1. Acquisition Cost of GPS Avionics	4-2

LIST OF FIGURES

3-1. GPS Avionics for High-Performance Aircraft	3-2
3-2. GPS Avionics for Low-Performance Aircraft	3-9
A-1. Typical Input Worksheet	A-3
A-2. Typical Model Output Data Sheet	A-4

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The Global Positioning System (GPS) is being developed for the military to provide, from a satellite-based positioning information system, accurate worldwide navigation capability that should meet or exceed the standards for navigating in the National Air Space (NAS).

As part of the ongoing program of the Federal Aviation Administration (FAA) to review new candidates for navigation, the Office of Systems Engineering Management (OSEM) is examining the GPS concept and has tasked ARINC Research Corporation, under contract DOT-FA76WA-3788, to develop probable costs of civil GPS avionics.

This study addressed only issues relating to the economic feasibility of a civil GPS concept by developing expected costs of avionics required for its operation.

1.2 PROJECT OVERVIEW

The objective of the analysis is to develop an independent assessment of the cost of avionics required to implement the GPS concept in the civil community on the basis of designs being developed for the military. To meet this objective, it has been necessary to analyze the various types of GPS avionics equipments being developed, identify the military-peculiar tactical requirements (e.g., antijam protection), and eliminate, where possible, military-peculiar capabilities that would not be required in civil applications. Further, the accuracies available from the GPS concept in many cases far exceed those necessary in today's civil air traffic control (ATC) and probably will not be required in near future ATC improvements. Therefore, a reduction in performance specifications of GPS avionics is possible, which should decrease the cost of civil equipments.

ARINC Research Corporation is developing the cost of civil GPS avionics using both the traditional method of cost estimating and by application of a commercially available pricing model. This report presents the cost estimating method, the constraints applied to ensure uniformity in the development of avionics costs, and the results of the application of the pricing model.

1.3 ORGANIZATION OF THE REPORT

The four chapters of this report address the techniques used in estimating the costs of system designs of the concept evaluated and give the results of applying the pricing model.

Chapter Two identifies the pricing model used in the study and discusses the parametric data required to execute the model.

Chapter Three is devoted to the evaluation of the systems and the costs of the avionics required for implementing each system.

Chapter Four presents the results of the evaluation and the expected cost of avionics required for system operation for each of the user communities.

Appendix A lists the input parameters used by the pricing model.

CHAPTER TWO

PRICING METHOD AND THE PRICE MODEL

The equipment costs developed in this study will provide a basis for comparing various concepts intended to improve navigation accuracy in the next generation of ATC systems. Careful development of these data is an essential step in the overall analysis of the alternatives. This chapter addresses the method used in the study and describes the model chosen for cost estimating and evaluation.

2.1 COST ESTIMATING METHOD

The model chosen for equipment pricing, the RCA Programmed Review of Information for Costing and Evaluation (PRICE), requires a set of parametric data inputs that properly define the module, or system, to be priced. The model was chosen because of its wide acceptance by branches of the Federal Government as a computer-based pricing model. Of the many input parameters required, the most critical cost-driving ones are the weight, volume, structural-electronic division, manufacturing complexities, and markups for overhead, G&A, and profit. Since manufacturing complexities vary among manufacturers in different fields (e.g., avionics for ARINC class or general aviation class equipments), a detailed characterization of each manufacturer expected to produce avionic equipment is necessary.

ARINC Research has studied the manufacturing complexities of several key manufacturers of avionics by thoroughly reviewing existing avionics, making visits and collecting data at various avionics plants, and frequently exercising the PRICE model to establish the sensitivities of the parametric data. To ensure accuracy in existing characterizations of equipment, all modules of a specific item of avionics were measured and weighed. The process was repeated on enough types of avionics to ensure a statistically sufficient sample.

The results were compiled and stored in ARINC Research data files and used in estimating the cost of the avionics considered in this study.

2.2 THE PRICE MODEL

PRICE is a computerized parametric cost-modeling technique developed by RCA. It estimates development and production costs on the basis of physical and economic descriptors of the systems evaluated. It compares new requirements to analogous histories with empirical data bases. PRICE efficiently stores, retrieves, and uses historical information. Effective use of empirical data allows classifying new ideas by relating them to past similar occurrences. The method provides the means of reducing empirical data to a few principal variables that can be adjusted for the economic and technological differences of the specific system.

2.2.1 Model Input Data

The model requires up to 40 parametric data inputs describing the physical and economic characteristics of the system or subassembly to be evaluated. When operated in the subassembly mode, the model requires similar inputs for all subassemblies and provides the means for final test and integration of the system. In general, the latter mode was employed for all the cost estimates in this study.

The physical descriptors included such key features as weight of structure and electronics, packaging densities, volumes, quantities to be produced, manufacturing complexities, and design requirements. Since the model is structured to provide a cost-per-pound based on densities and complexities, an accurate determination of the probable weight and volume of the subassembly being evaluated is essential.

The economic descriptors include such features as year of production, escalation rates, engineering schedules, production schedules, and management required during development and production. Schedules must be carefully selected because the final costs developed by the model are affected by the complexity of a product and the time allowed for its development and production. Other costs, such as those for management, tooling, or test equipment, have been normalized to the RCA data bank and are altered through sensitivity analyses and adaptation to specific manufacturers.

The key input parameters are listed in Table 2-1 in the format used throughout the study. Abbreviations and acronyms used are defined to provide an insight into the parametric data employed by the model. Appendix A provides a complete list of input parameters used by the model.

2.2.2 Model Output Data

The RCA PRICE model performs a series of evaluations based on the input parametric data and provides costs as a function of the elements associated with engineering and manufacturing for both development and production of a system or subassembly. Engineering costs include the cost of drafting, design, system management, project management, and data documentation required during system development and production. The costs are presented for the entire production quantity for the development and production period

Table 2-1. KEY PRICE PHYSICAL AND ECONOMIC DESCRIPTORS

Descriptor Acronym or Abbreviation	Description
QTY	Total quantity to be produced
WT	Weight of assembly (subassembly) in pounds
VOL	Volume of assembly (subassembly) in cubic feet
WS	Weight of structure (nonelectronic) of assembly in pounds
MCPLXS	Manufacturing complexity for structure
NEWST	Percent of new design required for structure
MCPLXE	Manufacturing complexity for electronics
NEWEL	Percent of new design required for electronics
CMPNTS	Number of electronic components
ECMPLX	Engineering complexity of assembly (subassembly)
PRMTH	Production period in months
LCURVE	Production learning curve
ECNE	Engineering change orders for electronics, in percent
ECNS	Engineering change orders for structure, in percent
YEAR	Year of technology (usual start of design/production)
ESC	Escalation rate in percent
PROJCT	Degree of project management support during engineering
DATA	Degree of data requirements
TLGTST	Degree of special tools and test equipment required for development
PLTFM	Factor for reliability testing, specification severity
SYSTEM	Degree of system engineering required
PPROJ	Degree of project management support during production
PDATA	Degree of data required during production
PTLGTS	Degree of special tools and test equipment required for production

on the basis of the data input parameter set and include the effect of inflation (escalation). Manufacturing is concerned primarily with the production of a system, but it also includes costs for prototype development and special tools or test equipment that might be required during development. As in the case of engineering, the output costs are for the entire production quantity with appropriate escalation.

During program execution, the model frequently compares schedules, densities, and other key input parameters with historical data in the RCA data banks. Abnormal inputs, such as too short development periods, are flagged and brought to the attention of the operator.

The output data sheet contains all the information used as the parametric input to the model; it also provides key parameters used in the computer evaluation for comparison with empirical data sets and mathematical patterns from the RCA library to monitor the reasonableness of the results. Finally, the output data sheet provides the expected cost estimated by the program, bounded by approximately two-sigma level-of-confidence costs. The confidence intervals, although available from the model results, are omitted from this study to keep it similar to other economic analysis reports used in the evaluation of future ATC alternatives. A copy of a typical model output data sheet is provided in Appendix A.

CHAPTER THREE

GLOBAL POSITIONING SYSTEM (GPS) CIVIL AVIONICS

The military-developed Global Positioning System may be the basis for worldwide future air navigation. Design goals for the most sophisticated versions of GPS require three-dimensional accuracies measured in meters. However, the civil aviation community has no foreseeable requirements for this degree of accuracy for en route and terminal use. In addition, the altitude information used in civil air traffic control is derived from pressure altimeters which, although less accurate at higher altitudes, indicate uniform relative altitudes for all aircraft in the same pressure region. Conversion to a different altitude reporting system would require all users of the airspace to convert simultaneously. This study recognizes that civil air traffic control does not require the three-dimensional accuracy possible with the proposed GPS; civil aircraft typically do not engage in high speed maneuvers standard for the military. As a result, it has been possible to select a GPS design more appropriate for civil aviation.

The design which best meets the needs of the civil community, providing positioning accuracies comparable to today's ground-based systems (e.g., VOR/DME) but on a worldwide basis and incorporating RNAV capability, is the medium-dynamic system referred to as the "Z" set. This set, designed for non-tactical cargo aircraft and tactical bombers and tankers, has been chosen for cost comparison for civil applications. The signal format, signal acquisition, and frequency conversion techniques, as well as data processing and display, have been retained without modification to assure the same performance as will be provided by the original equipment. Packaging techniques and environmental considerations have been altered to reflect the particular requirements of the commercial air carriers and general aviation. This chapter describes the packaging design modifications and develops the cost of GPS avionics by application of the pricing model.

3.1 AVIONICS COST DEVELOPMENT, HIGH-PERFORMANCE AIRCRAFT

The avionics required by high-performance aircraft using GPS as the navigation system consist of an antenna, preamplifier, receiver, and control and indicator panel (as shown in Figure 3-1). The antenna is assumed to be similar to that developed for military application with unit costs estimated for large production quantities. The unit-cost estimate for the antenna

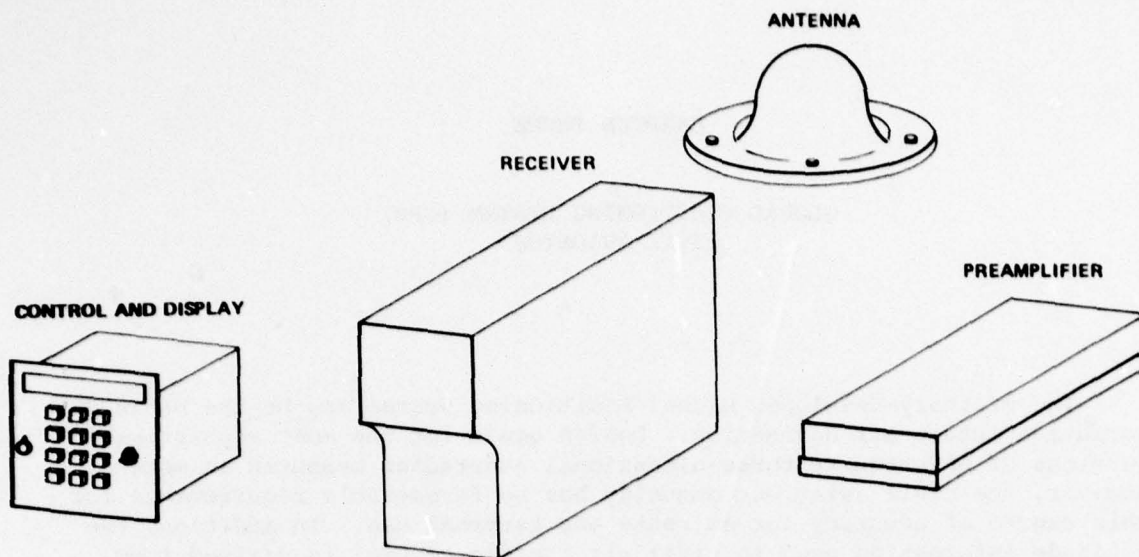


Figure 3-1. GPS AVIONICS FOR HIGH-PERFORMANCE AIRCRAFT

was based on data contained in the critical design review* documentation presented to SAMSO and extrapolated to production quantities by application of a 0.88 learning curve. The costs of the remaining avionics of the GPS system were estimated by the pricing model with parametric data inputs to the model obtained from details in the critical design review report and information provided by the engineering departments of SAMSO and Magnavox.

3.1.1 GPS Receiver

The adaptation of the "Z" set to air carrier use requires a standard 1/2 ATR short ARINC specification enclosure to house the eleven printed circuit boards and the RF assembly. Inputs to the receiver and outputs to the control and display device would be through a rear-mounted DPX connector. The boards constitute the receiver signal conditioning, the data processor, and the power supply with appropriate regulators. For evaluation purposes, none of the boards was redesigned or changed in physical appearance. However, the board-mounting technique and board-interconnect configuration were modified to reflect the standard practice of the airline industry. Component parts used in air carrier avionics meet the temperature requirements of military standards, although unpressurized operation at high altitudes is not mandatory. The resultant repackaged GPS receiver is less shock-proof than the original "Z" set counterpart, but still will meet all the applicable environmental requirements of RTCA Document DO-160.

*NAVSTAR Global Positioning System Phase I User Equipment, Set Z, Critical Design Review, 13 December 1977; Magnavox APD, General Dynamics.

Table 3-1 presents the physical and economic descriptors of the GPS receiver. Critical parameters, such as the electronic and structural complexity data, were derived by first reconstructing the military version of the "Z" set in PRICE terminology and exercising the model to obtain the cost data presented in the critical design review document. The key parameters of the "Z" set were then compared with empirical RCA data files to identify the degree of higher or lower complexity than those in the files. RCA data and ARINC Research data on air carrier avionics manufacturing complexities were also compared to identify the variation with empirical data. As a final step, ARINC Research data were accordingly modified where more complex manufacturing practices were identified through the comparison of the "Z" set and empirical data. Economic descriptors used in the analysis are those which have been developed in past applications of the PRICE model to air carrier type avionics manufacturing.

Production quantities per manufacturer were set at 3000 units over a three-year period to maintain a consistent base for comparison with other cost estimates developed for the FAA in the evaluation of alternatives. These quantities were considered sufficient to complete the production learning curve and amortize development and start-up costs. The results of the analysis are presented in 1977 dollars with zero inflation over the period of development and manufacturing.

Table 3-2 summarizes the PRICE outputs by subassembly costs for development and production and gives cumulative costs. The oscillator module is considered a purchase item and not subject to manufacturer's development costs. The last equipment entry, Test and Integration, is a mandatory input when a system cost is developed by subassemblies. Test and Integration accounts for the final assembly of a unit, machining of interface components, providing of power connections, alignment and tuning of electrical subsystems, and the performance of the final functional test of the system. (Software development and processor programming, necessary for the GPS receivers, are not included in the costs developed in this study.) The factory price is the cost of manufacturing with appropriate G&A and profit included; it is the expected selling price to air carriers and distributors. The selling (list) price is the normal cost to owners of private aircraft buying limited quantities of the product.

3.1.2 GPS Control and Display

The control and display unit recommended for air carrier application is functionally identical and physically similar to the unit developed for military applications. Packaging requirements have been modified to reflect the normal practice of air carrier avionics manufacturing. The unit consists of eight 7-segment LEDs, two 5 x 7 dot matrix LEDs, 10 waypoint number readouts (including 0 for present position), keyboard for data entry, rotary data selector switch, and miscellaneous secondary control and indicator functions. Four printed circuit boards included in the housing provide the necessary drivers, displays, control, power regulation, and interface with the receiver. The unit is designed for mounting in a prominent location on the forward pedestal of a flight deck.

Table 3-1. PARAMETER VALUES FOR GPS RECEIVER, HIGH-PERFORMANCE AIRCRAFT												
Parameter	Parameter Value											
	Processor Card	EPROM Card	Receiver I/O	Memory Control	Receiver Baseband	Receiver Control	C/A Code	CDU Interface	RF/IF Module	Synthesizer	RF Assembly	Power Supply
QTY	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
WT	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.0	1.0	0.422
VOL	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.01	0.03	0.03	0.005
WS	-	-	-	-	-	-	-	-	-	0.483	0.483	-
MCPLXS	-	-	-	-	-	-	-	-	-	6.341	6.341	-
NEWST	-	-	-	-	-	-	-	-	-	1	1	-
MCPLXE	8.606	8.817	7.789	8.12	8.926	7.726	8.104	7.331	8.951	8.167	8.253	7.445
NEWEL	1	1	1	1	1	1	1	1	1	1	1	0.5
CHPNTS	65	57	76	95	369	127	131	28	123	333	6	249
ECMPLX	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.5	0.9
PRMTH	36	36	36	36	36	36	36	36	36	36	36	36
LCURVE	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865
ECNE	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-
ECNS	-	-	-	-	-	-	-	-	-	0.01	0.01	-
YEAR	1977	1977	1977	1977	1977	1977	1977	1977	1977	1977	1977	1977
ESC	0	0	0	0	0	0	0	0	0	0	0	0
PROJCT	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DATA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
TLGTST	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PLTGM	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
SYSTEM	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PPROJ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PDATA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PTLOTS	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table 3-2. GPS RECEIVER, HIGH PERFORMANCE AIRCRAFT (1977 DOLLARS)			
Equipment	Cost Factors		
	Development (Dollars/Unit)	Production (Dollars/Unit)	Total (Dollars)
Processor Card	60.87	834.62	895
EPROM Card	70.57	1,015.69	1,086
Receiver I/O	41.78	406.78	449
Memory Control	51.95	545.77	598
Receiver Baseband	73.06	1,119.55	1,193
Receiver Control	39.97	384.69	425
C/A Coder	51.48	538.06	590
CDU Interface	35.09	271.25	306
RF/IF Module	81.69	1,149.73	1,231
Synthesizer	63.89	591.32	655
RF Assembly	67.09	632.37	699
Power Supply	17.35	223.75	241
Oscillator	-	225.00	225
Enclosure and Chassis	17.36	875.54	893
Test and Integration	9.64	316.63	326
Factor Price			9,812
Distributor Markup			2,944
List Price			12,756

Table 3-3 presents the physical and economic descriptors required by the PRICE model for evaluation of the control and display unit. The same procedure as used for the GPS receiver has been followed in developing critical parametric data for the unit. Enclosure and chassis data were developed from information for similar control units documented in ARINC Research data banks.

Table 3-4 gives the results of the PRICE evaluation. Production quantities are consistent with the assumption that only one unit will be required with each receiver. The factory price and list price data show the expected cost to multiple and single unit buyers.

Table 3-3. PARAMETER VALUES FOR CONTROL AND DISPLAY, HIGH-PERFORMANCE AIRCRAFT					
Parameter	Parameter Value				
	Regulator	Display Board	Driver Board	Control Board	Enclosure and Chassis
QTY	3000	3000	3000	3000	3000
WT	0.233	0.234	0.234	0.234	2.785
VOL	0.008	0.003	0.003	0.003	0.082
WS	-	-	-	-	2.785
MCPLXS	-	-	-	-	6.294
NEWST	-	-	-	-	0.8
MCPLXE	7.056	7.791	7.755	8.239	-
NEWEL	0.3	1	1	1	-
CMPNTS	6	19	42	41	-
ECMPLX	0.4	0.9	0.7	1.0	0.9
PRMTH	36	36	36	36	36
LCURVE	0.865	0.865	0.865	0.865	0.865
ECNE	0.01	0.01	0.09	0.12	-
ECNS	-	-	-	-	0.03
YEAR	1977	1977	1977	1977	1977
ESC	0	0	0	0	0
PROJECT	0.5	0.5	0.5	0.5	0.5
DATA	0.5	0.5	0.5	0.5	0.5
TLGTST	0.3	0.3	0.3	0.3	0.3
PLTFM	1.7	1.7	1.7	1.7	1.7
SYSTEM	0.3	0.3	0.3	0.3	0.3
PPROJ	0.5	0.5	0.5	0.5	0.5
PDATA	0.5	0.5	0.5	0.5	0.5
PTLGTS	0.3	0.3	0.3	0.3	0.3

Table 3-4. GPS CONTROL AND DISPLAY, HIGH PERFORMANCE AIRCRAFT (1977 DOLLARS)			
Equipment	Cost Factors		
	Development (Dollars/Unit)	Production (Dollars/Unit)	Total (Dollars)
Regulator	2.70	95.43	98
Display Board	23.35	190.73	214
Driver Board	19.24	181.62	201
Control Board	35.69	282.41	318
Enclosure and Chassis	9.64	392.62	402
Test and Integration	1.75	64.86	67
Factory Sell Price			1,300
Distributor Markup			390
List Price			1,690

3.1.3 GPS Preamplifier

The preamplifier required for GPS operation is a remotely mounted (at antenna), RFI-sealed, low-noise-figure device with band-pass cavity filters and an active gain stage. The unit receives power for the active elements through the rf cables from the GPS receiver. The PRICE parametric data descriptors class the unit as predominantly a structural device, and it has been evaluated as a single assembly. Economic parameters used are the same as those applied to the receiver and control assemblies. The results of the PRICE analysis of the preamplifier for production quantities of 3000 units are given in the summary table of the GPS avionics system cost.

3.1.4 Cost Summary

The cost of avionics required by high-performance aircraft for implementation of the GPS navigation system is given in Table 3-5. The cost factors shown are the total development dollars for each piece of avionics and the per unit production costs of the equipment as computed by the PRICE model. The "Total" column gives the production cost and development cost amortized over 3000 units of production. The factory price is the expected cost of a single (non-redundant) system purchased by an air carrier or distributors. The list price includes a mark-up for distribution and is the expected cost to single aircraft owners requiring high-performance avionics.

Table 3-5. GPS AVIONICS, HIGH PERFORMANCE AIRCRAFT, SINGLE SYSTEM			
Equipment	Cost Factors		
	Development* (Dollars)	Production (Dollars/Unit)	Total (Dollars/Unit)
Receiver	1,998,000	9,131	9,812
Control and Display	277,139	1,208	1,300
Preamplifier	170,597	671	727
Antenna	75,000	205	230
Factory Sell Price			12,069
Distributor Markup			3,621
List Price			15,690
*Development costs assumed amortized over 3000-unit production quantity.			

3.2 AVIONICS COST DEVELOPMENT, LOW-PERFORMANCE AIRCRAFT

The avionics required by low-performance aircraft using GPS as the navigation system consist of an antenna with built-in preamplifier, a remotely mounted receiver, and a console mounted control and display panel as shown in Figure 3-2. The performance of the GPS system installed in this class of aircraft is expected to be similar to that considered for high-performance aircraft. In order to maintain the same performance standards, the schematic designs used for high-performance avionics were retained for this class of avionics, although considerable redesign in packaging of subassemblies and assemblies was necessary to reflect the packaging practices of the general aviation manufacturers. This section presents the cost development of the receiver and display units as estimated by the PRICE model. The cost of the antenna with built-in preamplifier was adapted from data on a recently developed combined antenna-RF unit for general aviation aircraft. The cost of the L-band antenna preamplifier is expected to be similar to what is presented in this report.

3.2.1 GPS Receiver

The GPS receiver expected to be used by single and light twin engine aircraft contains all the electronics required for signal acquisition, frequency conversion, data processing, power supplies, and information generation to drive the display unit. The electronics will be mounted on plug-in printed circuit cards and arranged to perform the receiver IF functions, processing, frequency synthesizing, and power supply regulation. Six plug-in cards in addition to the enclosed RF module are envisioned to perform all

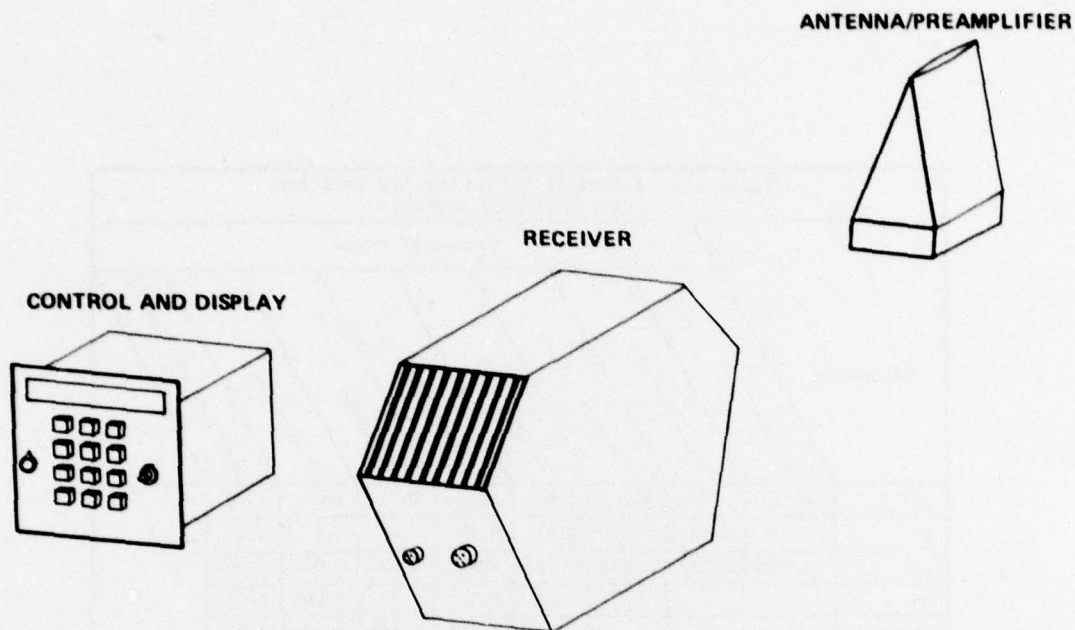


Figure 3-2. GPS AVIONICS FOR LOW-PERFORMANCE AIRCRAFT

the functions detailed for the high-performance receiver. Because of lower shock and vibration requirements for general aviation avionics the cards can be larger and can accommodate more functions per card than their high-performance equivalents. A lower cost oscillator will be used, which meets the stability requirements of GPS oscillators, but not the environmental requirements of high-performance units. The packaging of the receiver is unrestricted, typical of the enclosures and the practice of general aviation manufacturers.

Table 3-6 gives the physical and economic descriptors of the GPS receiver. Critical parameters, such as electronic and structural complexity data, were developed in comparison with RCA empirical data and with ARINC Research data files for typical general aviation avionics, and appropriate corrective upgrading was applied to reflect the degree of complexity associated with GPS. The economic descriptors used in the analysis are those that have been developed in past applications of the PRICE model for this class of avionics manufacturing.

The results of the PRICE analysis of the low-performance GPS receiver are shown in Table 3-7. The development costs are shown for each module and have been amortized over a production quantity of 3000 units. The oscillator is considered to be an outside-purchased item, not requiring development. Test and integration costs reflect the expense of final assembly and factory testing of the completed GPS receiver. The factory sell price is the cost to distributors handling the product. A typical distributor markup of 100 percent has been applied to the sell price to estimate the list price, which private aircraft owners would pay for a GPS receiver.

Table 3-6. PARAMETER VALUES FOR GPS RECEIVER, LOW-PERFORMANCE AIRCRAFT									
Parameter	Parameter Value								
	Receiver	Processor #1	Processor #2	Processor #3	Synthesizer	RF Module	Power Supply	Enclosure and Chassis	
QTY	3000	3000	3000	3000	3000	3000	3000	3000	
WT	0.63	0.63	0.63	0.63	0.48	0.48	0.4	3.0	
VOL	0.023	0.023	0.023	0.023	0.008	0.008	0.005	0.203	
WS	-	-	-	-	0.1	0.1	0.005	3.0	
MCPLXS	-	-	-	-	4.321	4.321	4.321	4.68	
NEWST	-	-	-	-	0.1	0.1	0.1	0.2	
MCPLXE	6.037	6.299	6.299	6.299	6.788	6.037	5.714	-	
NEWEL	1	1	1	1	0.7	0.7	0.3	-	
CMPNTS	228	387	295	236	186	81	31	-	
ECMPLX	1.0	1.5	1.0	0.9	0.7	0.7	0.4	0.3	
PRMTH	36	36	36	36	36	36	36	36	
LCURVE	0.865	0.865	0.865	0.865	0.865	0.865	0.865	0.865	
ECNE	0.05	0.05	0.05	0.05	0.05	0.05	0.005	-	
ECNS	-	-	-	-	0.005	0.005	0.005	0.01	
YEAR	1977	1977	1977	1977	1977	1977	1977	1977	
ESC	0	0	0	0	0	0	0	0	
PROJECT	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
DATA	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
TLGTST	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	
PLTFM	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	
SYSTEM	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
PPROJ	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
PDATA	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
PTLGTS	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	

Table 3-7. GPS RECEIVER, LOW-PERFORMANCE AIRCRAFT (1977 DOLLARS)			
Equipment	Cost Factors		
	Development (Dollars/Unit)	Production (Dollars/Unit)	Total (Dollars)
Receiver	21.98	109.37	131
Processor #1	55.07	232.45	287
Processor #2	23.38	137.38	161
Processor #3	23.38	137.38	161
Synthesizer	13.30	144.59	158
RF Module	11.21	78.81	90
Oscillator	-	118.57	119
Power Supply	3.61	54.21	58
Enclosure and Chassis	1.12	110.29	111
Test and Integration	2.49	94.59	97
Factory Sell Price			1,373
Distributor Markup			1,373
List Price			2,746

3.2.2 GPS Control and Display

The control and display unit recommended for the low-performance general aviation aircraft is functionally identical to that described in Section 3.1.2, but the packaging and quality of components is consistent with the practice of the general aviation manufacturers. The unit would be designed to be installed in the flight console of aircraft for easy access and readability. Electronics required for lamp drivers, displays, input data processing, power regulation, and interface with the receiver would be housed in the unit.

Table 3-8 presents the physical and economic descriptors required by the PRICE model for evaluation of the control and display unit. The same procedure as used for the receiver has been followed in developing critical parametric data for the unit. Enclosure and chassis data were developed from information related to similar units documented in ARINC Research data banks.

The results of the evaluation appear in Table 3-9. Production quantities are based on the assumption that only one unit will be required with each receiver. The list price shown includes the normal markup for distribution and is the expected cost to single aircraft owners.

Table 3-8. PARAMETER VALUES FOR CONTROL AND DISPLAY, LOW-PERFORMANCE AIRCRAFT					
Parameter	Parameter Value				
	Regulator	Display Board	Driver Board	Control Board	Enclosure and Chassis
QTY	3000	3000	3000	3000	3000
WT	0.233	0.234	0.234	0.234	1.785
VOL	0.008	0.003	0.003	0.003	0.082
WS	-	-	-	-	1.785
MCPLXS	-	-	-	-	4.833
NEWST	-	-	-	-	0.8
MCPLXE	5.288	6.023	5.967	6.471	-
NEWEL	0.3	1	1	1	-
CMPNTS	6	19	42	41	-
ECMPLX	0.4	0.9	0.7	1.0	0.9
PRMTH	36	36	36	36	36
LCURVE	0.865	0.865	0.865	0.865	0.865
ECNE	0.01	0.05	0.05	0.06	-
ECNS	-	-	-	-	0.05
YEAR	1977	1977	1977	1977	1977
ESC	0	0	0	0	0
PROJCT	0.3	0.3	0.3	0.3	0.3
DATA	0.3	0.3	0.3	0.3	0.3
TLGTST	0.2	0.2	0.2	0.2	0.2
PLTFM	1.6	1.6	1.6	1.6	1.6
SYSTEM	0.3	0.3	0.3	0.3	0.3
P PROJ	0.3	0.3	0.3	0.3	0.3
P DATA	0.3	0.3	0.3	0.3	0.3
PTLGTS	0.2	0.2	0.2	0.2	0.2

Table 3-9. CONTROL AND DISPLAY, LOW-PERFORMANCE AIRCRAFT (1977 DOLLARS)			
Equipment	Cost Factors		
	Development (Dollars/Unit)	Production (Dollars/Unit)	Total (Dollars)
Regulator	1.76	25.28	27
Display Board	16.60	48.77	65
Driver Board	13.60	46.53	60
Control Board	19.94	71.29	91
Enclosure and Chassis	4.84	85.00	90
Test and Integration	0.76	28.05	29
Factory Sell Price			362
Distributor Markup			362
List Price			724

3.2.3 Cost Summary

The cost of avionics required by low-performance aircraft for implementation of the GPS navigation system is presented in Table 3-10. Total development costs, unit production costs, and factory sell prices with development amortized over the 3000-unit production quantity are shown for the three subsystems making up the GPS concept. The list price of \$3,620 per aircraft is the expected acquisition cost to single and light twin engine aircraft owners to obtain the navigational capability defined by the military "Z" set.

Table 3-10. GPS AVIONICS, LOW-PERFORMANCE AIRCRAFT, SINGLE SYSTEM			
Equipment	Cost Factors		
	Development* (Dollars)	Production (Dollars/Unit)	Total (Dollars/Unit)
Receiver	461,362	1,218	1,373
Control and Display	172,505	305	362
Antenna with Preamplifier	15,000	70	75
Factory Sell Price			1,810
Distributor Markup			1,810
List Price			3,620
*Development costs assumed amortized over 3000-unit production quantity.			

CHAPTER FOUR

RESULTS OF EVALUATION

The study has developed costs of avionics based on a uniform approach to estimating costs with the assistance of a pricing model. The data used in exercising the model were developed through detailed analyses of systems of several leading avionics manufacturers producing either high-performance aircraft equipment or low-performance aircraft equipment and modified to reflect the increasing complexities expected from introduction of a sophisticated new concept like the Global Positioning System. This chapter summarizes the results of the evaluation of the GPS concept for the two classes of civil aviation users, high performance and low performance.

4.1 CONCEPT EVALUATED

The adaptation of the military-developed "Z" set as a candidate for civil application of GPS has resulted in a navigation system that will provide accurate positioning information to aircraft in flight as well as the capability equivalent to an area navigation (RNAV) system. The RNAV function is made possible by the system's capability to provide waypoint inputs from the control panel and use microprocessors in the control and display unit to interact with the positioning information accumulated by the receiver. Although this feature adds to the cost of the system, the benefits derived could overshadow those costs, especially when compared with the cost of an existing RNAV system dependent on ground-generated positioning information. The design evaluated in this study was intentionally proportioned between the receiver and control units to provide an insight into the cost of GPS if RNAV capability was not required. The receiver would remain unchanged if the same level of accuracy and performance as the "Z" set provides is desired. The control and display unit would be greatly simplified because only display drivers and receiver interface electronics would be required.

4.2 COST DATA OF CONCEPT EVALUATED

The avionics costs developed by application of the pricing model are summarized in Table 4-1. The values indicate the probable selling price per item of avionics to the air carriers and to high-performance and

Table 4-1. ACQUISITION COST OF GPS AVIONICS			
Equipment	Cost (in Dollars) by User Category		
	Air Carrier	High-Performance General Aviation	Low-Performance General Aviation
Receiver	9,812	12,756	2,746
Control and Display	1,300	1,690	724
Preamplifier	727	945	150
Antenna	230	299	
Total Cost	12,069	15,690	3,620

low-performance general aviation aircraft owners. Appropriate markups for distribution have been included on the basis of known or expected practices of the avionics manufacturers. All costs are based on the 1977 dollar without inflation. Potential variability in costs exists as a function of the production volume dictated by user demand. However, the costs of alternatives can be compared because the cost of GPS avionics was evaluated with a uniform production quantity used in other studies performed by ARINC Research for the FAA.

APPENDIX A

RCA PRICE MODEL INPUT PARAMETERS

The appendix presents a listing of the input parameters used by the RCA PRICE model. Figure A-1 shows a typical input worksheet; Figure A-2 shows an example of a typical model output data sheet.

PRICE System
Input Worksheet

RCA Government and
Commercial Systems

Item	Date				
PROM CARD					
	QTY	PROTOS	WT	VOL	MODE
General	3000	3	.601	.0144	1
	QTYSYS	INTEGE	INTEGS	AMULTE (%)	AMULTM (%)
	1	.3	.3	138000	138000
Mechanical/ Structural	WS	MCPLXS	PRODS	NEWST	DESRPS
	.001	6.2	0	0	0
	USEVOL	MCPLXE	PRODE	NEWFL	DESRPE
Electronics	.99	8.817	0	1.0	2
	PWR	CMPTES	CMPIG	PWRFAU	CMPEFF
	6.0	57	0	0	1.0
	ENMTHS	ENMTHP	ENMTHI	ECMPLX	PRNF
Engineering	1	12	14	1.0	.3
	PRMTHS	PRMTHP	LCURVE	ECNE	ECNS
Production	12	48	.865	.01	.01
Purchased Item (Mode 3)	WS	BVCOST	LCURVE	MODES 1. PRINT TOTALS 2. E-M ITEM 3. MCHN ITEM 4. PURCH ITEM 5. GFE ITEM 6. INTEGRATE TEST 7. MODIFIED PURCH ITEM 8. MODIFIED GFE ITEM 9. PARASYN 10. E-M ITEM CALCD WT & VOL 11. GEOSYN	
GFE (Mode 4)	WS	MCPLXE	MCPLXS		
Additional Data (Modes 9 & 10)	MCONST	MEXP	WECE	TARCST (Mode 10 only)	
	YEAR	ESC	PROJECT	DATA	TLGTST
Global	1977	0	.5	.5	.3
	PLTFM	SYSTEM	PPROJ	PDATA	PTLGTS
	1.7	.3	.5	.5	.3

Notes:

GC 1595 275

Figure A-1. TYPICAL INPUT WORKSHEET

PROCESSOR EPROM

INPUT DATA

ELECTRONICS

USEVOL	0.990	MCPLXE	8.817	PRODE	0.000	NEMEL	1.000	DESRPE	2.000
PWR	6.000	CMPTS	57.	CMPID	0.000	PWRFAC	0.000	CMPEFF	0.000

ENGINEERING

ENMTHS	1.0	ENMTHP	12.0	ENMTHT	14.0	ECMLX	1.000	PRNF	0.300
--------	-----	--------	------	--------	------	-------	-------	------	-------

PRODUCTION

PRMTHS	12.0	PRMTHF	48.0	LCURVE	0.865	ECNE	0.010	ECNS	0.010
--------	------	--------	------	--------	-------	------	-------	------	-------

GLOBAL

YEAR	1977.	ESC	0.00%	PROJCT	0.500	DATA	0.500	TLGTST	0.300
PLATFM	1.700	SYSTEM	0.300	PRPDJ	0.500	PDATA	0.500	PTLGTS	0.30

PROGRAM COST

DEVELOPMENT

PRODUCTION

TOTAL COST

ENGINEERING

DRAFTING	40475.	433.	40908.
DESIGN	134050.	1467.	135517.
SYSTEMS	5461.	0.	5461.
PROJ MGMT	9441.	74544.	83985.
DATA	2565.	3090.	5655.
SUBTOTAL (ENG)	191992.	79534.	271525.

MANUFACTURING

PRODUCTION	0.	2870753.	2870753.
PROTOTYPE	18737.	0.	18737.
TOOL-TEST EQ	969.	96777.	97745.
SUBTOTAL (MFG)	19706.	2967530.	2987235.

TOTAL COST	211697.	3047064.	3258761.
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VOL	0.014	AVCOST	956.92	TOTAL AV	PROD COST	1015.69	LCURVE	0.865	
WT	0.601	ECNE	0.010	ECNS	0.010	DESRPE	0.159	DESRPS	0.000

MECH/STRUCT

MS	0.001	MSCF	0.069	MECID	0.000	PRODS	6.525	MCPLXS	6.200
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ELECTRONICS

ME	0.600	MECF	42.088	CMPID	0.000	PRODE	4.847	MCPLXE	8.817
PWR	6.000	CMPTS	57.			PWRFAC	0.565	CMPEFF	3.550

SCHEDULES

ENMTHS	1.000	ENMTHP	12.000	ENMTHT	14.000	ECMLX	1.000	PRNF	0.300
PRMTHS	12.000	PRMTHF	48.000	AVER. PROD RATE PER MONTH					83.333

COST RANGES

DEVELOPMENT

PRODUCTION

TOTAL COST

FROM	192431.	2696027.	2888458.
CENTER	211697.	3047064.	3258761.
TO	237871.	3459016.	3696888.

Figure A-2. TYPICAL MODEL OUTPUT DATA SHEET